Interaction of the Kuroshio with the East and the South China Seas and Nonlinear Wave Dynamics in the South China Sea

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LONG TERM GOALS

The long-term objective is to understand the dynamics of the several physical processes that occur in the China Seas with the coordinated use of several tools, some of which already developed by ONR: a numerical model, a Surface Velocity Program (SVP) drifters array and surface drifters are configured to gather enhanced data i.e. drifting thermistor chains (ADOS-V) fitted with profiling ADCP's. This research contributes to a more realistic prediction of this complex physical environment in area of strategic importance for PACFLEET operations.

OBJECTIVES

The first objective is to obtain accurate velocity measurements at 15 m depth in the China Seas and in the Luzon Strait region to achieve more accurate Fall and Winter measurements of the existing current systems and of the upper ocean mass transport through the Luzon Strait. The second objective is to utilize drifting platforms to make velocity and temperature profile observations of high amplitude, short period internal waves and compute their propagation velocity. The third objective is to use the existing and new datasets of surface circulation to compare with the results of the ROMS numerical model to evaluate the model ability to reproduce a realistic flow field.

APPROACH

To accomplish the first objective, SVP drifters were assembled in Korea and were deployed from 2003 through 2006 in the Luzon Strait region during the Kuroshio inflow regime of the October-January period. In the 3rd year, the currents at 150 m were also measured with drifters. These measurements determine accurately the current systems of the SCS and aspects of the dynamics of the in-and-out flow through the Luzon Strait. The drifter's data analysis is being performed by Dr.

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14. ABSTRACT
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Luca Centurioni. Dr. Centurioni and Dr. Niiler performed the interpretations of the drifter data and the comparison with the model outputs together with Dr. Lee. Regarding the Internal waves experiment, Dr. Luca Centurioni and Prof. Peter Niiler have advanced the interpretation of the data collected during the NLIWI ’05 pilot experiment and NLIWI ’07 main experiment with the overall goal of measuring the non-linear terms of the IW flow. Dr. Lee has completed the model simulations and performed the analysis of the results with Dr. Niiler.

WORK COMPLETED IN YF’08

Circulation studies in the South and East China Seas: observations

Having completed the release of SVP drifters in the Luzon Strait, we have continued and finished the analysis of circulation in the northern South China Sea. See results.

NLIWI’ 07

The data from the drifting thermisthor chains deployed in April 2007 and beginning of May 2007 in the South China Sea were analyzed. See results.

RESULTS

Surface currents in the northern South China Sea

Velocity measurements at 15 m depth from Surface Velocity Program drifters (Figure 1) were used to measure the mean geostrophic circulation in the northern South China Sea during the Winter Monsoon. The Ekman flow (v_e) was subtracted from drifter’s velocity (v) to infer the geostrophic component (Figure 2). The cyclonic geostrophic velocity field extends into the southern Luzon Strait. The Ekman flow was found to be nearly zonal and comparable to the zonal geostrophic flow. Drifter speeds are used to quantify the strong jets that occur in the South China Sea (whose locations are marked by A, B and C in Figures 1 and 3), one of which develops off the coast of Vietnam. Such current is concentrated inshore of the 200m isobaths, with mean speeds in excess of 1 ms^{-1}, and appears to be in semi-geostrophic balance, the nonlinear terms being large compared to the Coriolis term in the meridional momentum equation. The Ekman pumping velocity computed from the wind stress curl offer a qualitative explanation of the existence and behavior of such jet (Figure 3).

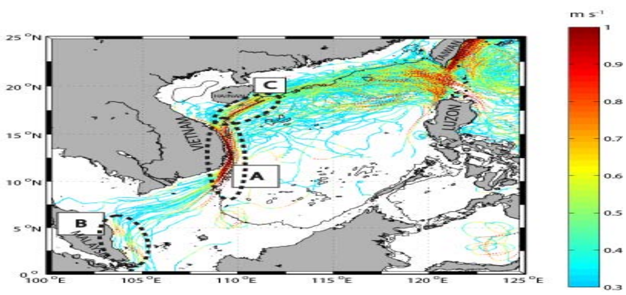

Figure 1: 68,549 six hourly location (from 9/11/1987 to 12/31/2007) of SVP drifters color coded in accordance with their instantaneous speeds. The drifter velocity time series were filtered with a 36 hour wide running average filter. The 200 m bathymetry contours are shown.

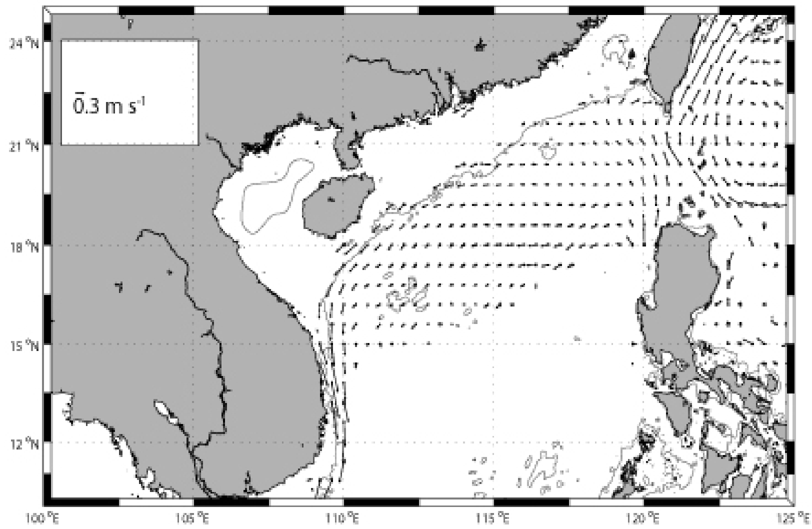

Figure 2: Mean $\vec{v} - \vec{v}_E$ field (0.4° X 0.6°, ONDJ) at 15 m depth from 11/12/1999 to 12/31/2007, computed over 52,393 six hourly observations. The pre-averaging operation yielded 14,172 nearly-independent velocity observations. Vectors computed from less than five pre-averaged observations are not shown. The 200 m bathymetry contours are shown.

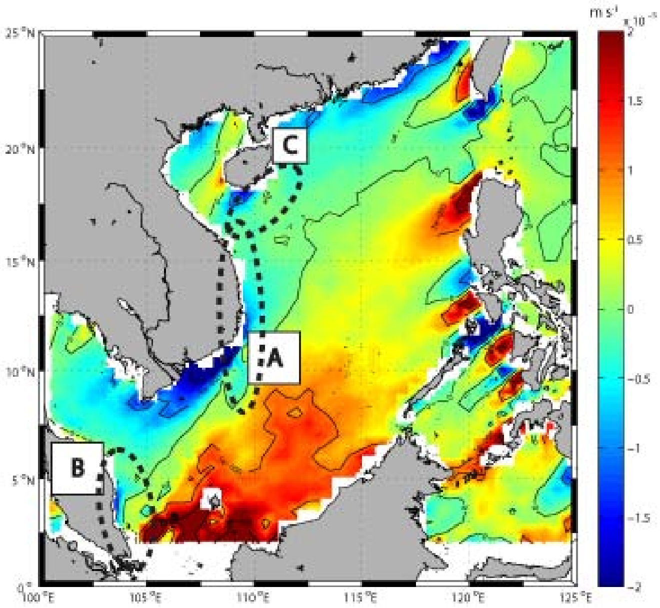

Figure 3: Mean Ekman pumping computed from wind-stress curl data for the months of November and December, from November 1997 through December 2007.

NLIWI

A new methodology by which physical properties of NLIWs can be observed from an array of drifting autonomous instruments was developed. Since the ADOS-V (Figure 4) is a light-weight device, relatively low cost and can be configured to be deployed by air, similar systems are also being used to gather information in the wake of hurricanes and typhoons. Other applications of this methodology may include observations of horizontally and vertically coherent oceanographic phenomena in the upper layer that require closely spaced array, such as the study of air-sea interaction processes.

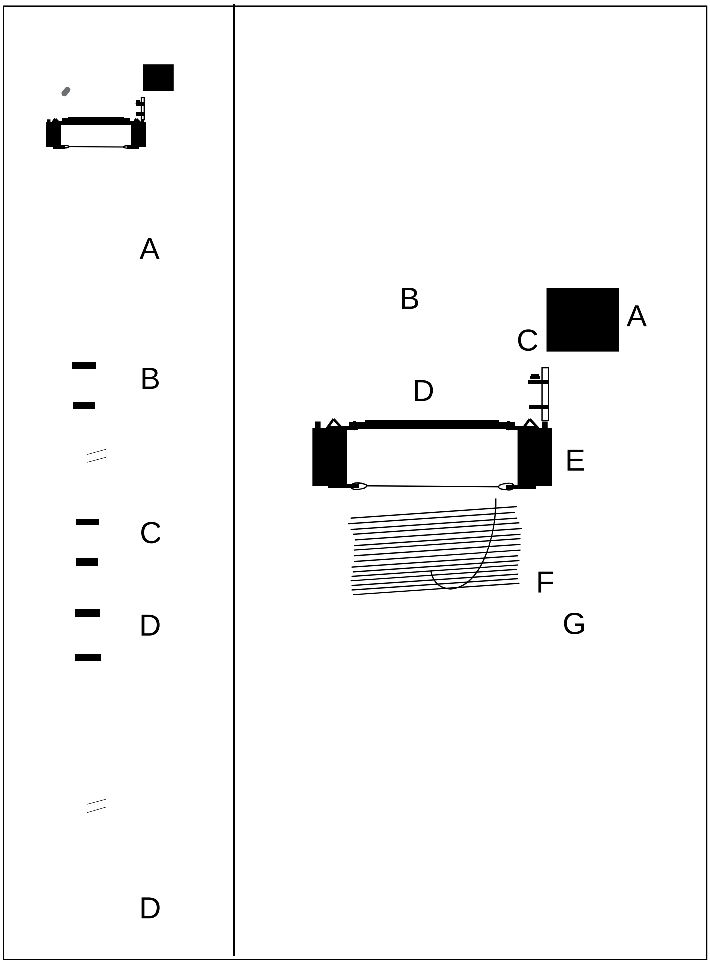

Figure 4. ADOS-V schematic. Left: the surface element is connected to a tether on which the temperature and pressure sensors (A), one 1MHz Aquadopp at 25 m depth (B), two 400 KHz Aquadopps (C and D) at 110 m depth and a 20 Kg weight (D) are attached. The spacing between the temperature and pressure sensors is approximately 10 m. Right: the ADOS-V tether is wrapped around a wooden reel (F) which is mounted on a pallet through a spinning wheel. The spherical buoy (D) is mounted on a rectangular cross-section toroidal anodized aluminum buoy (E). A flag (a) and a strobe light (C) are attached to the aluminum buoy together with a bridle used for recovering the ADOS-V.

High quality three-dimensional velocity and temperature measurements were obtained from the ’07 deployments (Figure5, 6 and 7) for the three observed wave groups, and the direction at which the waves propagate was determined very accurately (Tables 1 to 3) by measuring points of equal phase of the propagating waves across the ADOS-V array. In the case of the strong LIW this computation only requires good quality GPS positions, which can be obtained with very inexpensive technology.

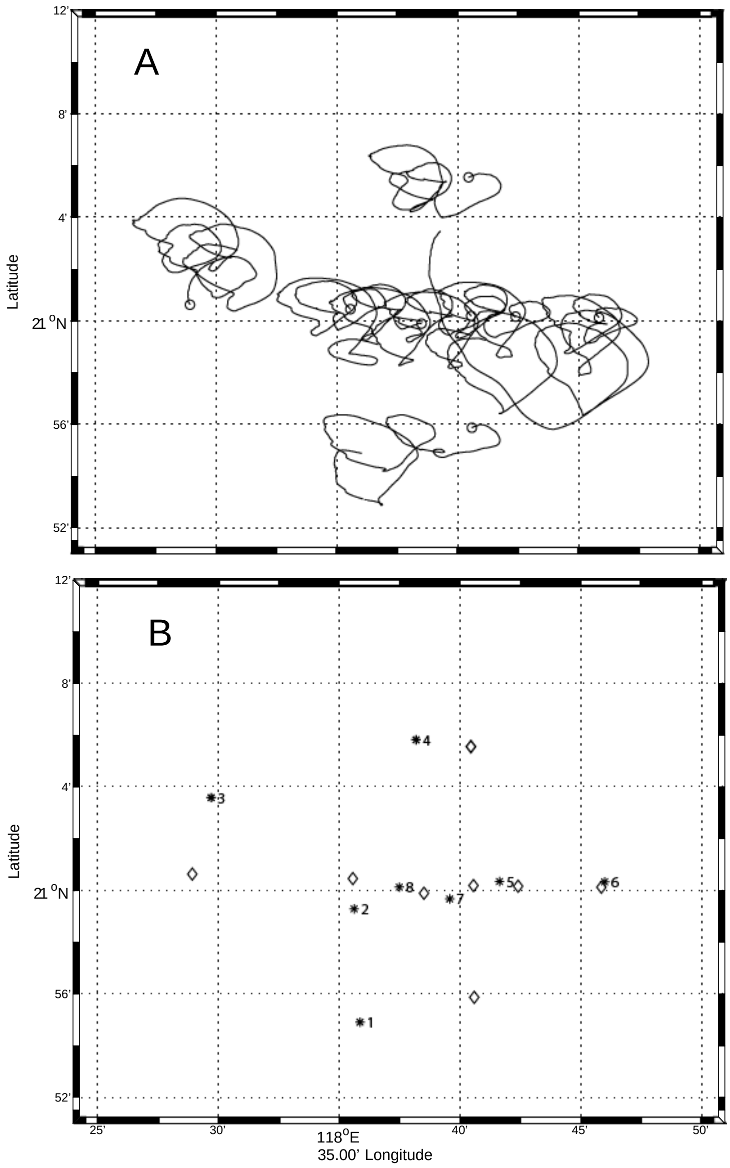

Figure 5. A: tracks of the eight ADOS-V's (nodes) from May 2, 2007, 17:28 UTC to May 7, 2007, 10:27 UTC. B: Initial position of the array (diamonds) and final position (asterisks) when the first node of the array was recovered on May 5, 2007, 23:56 UTC.

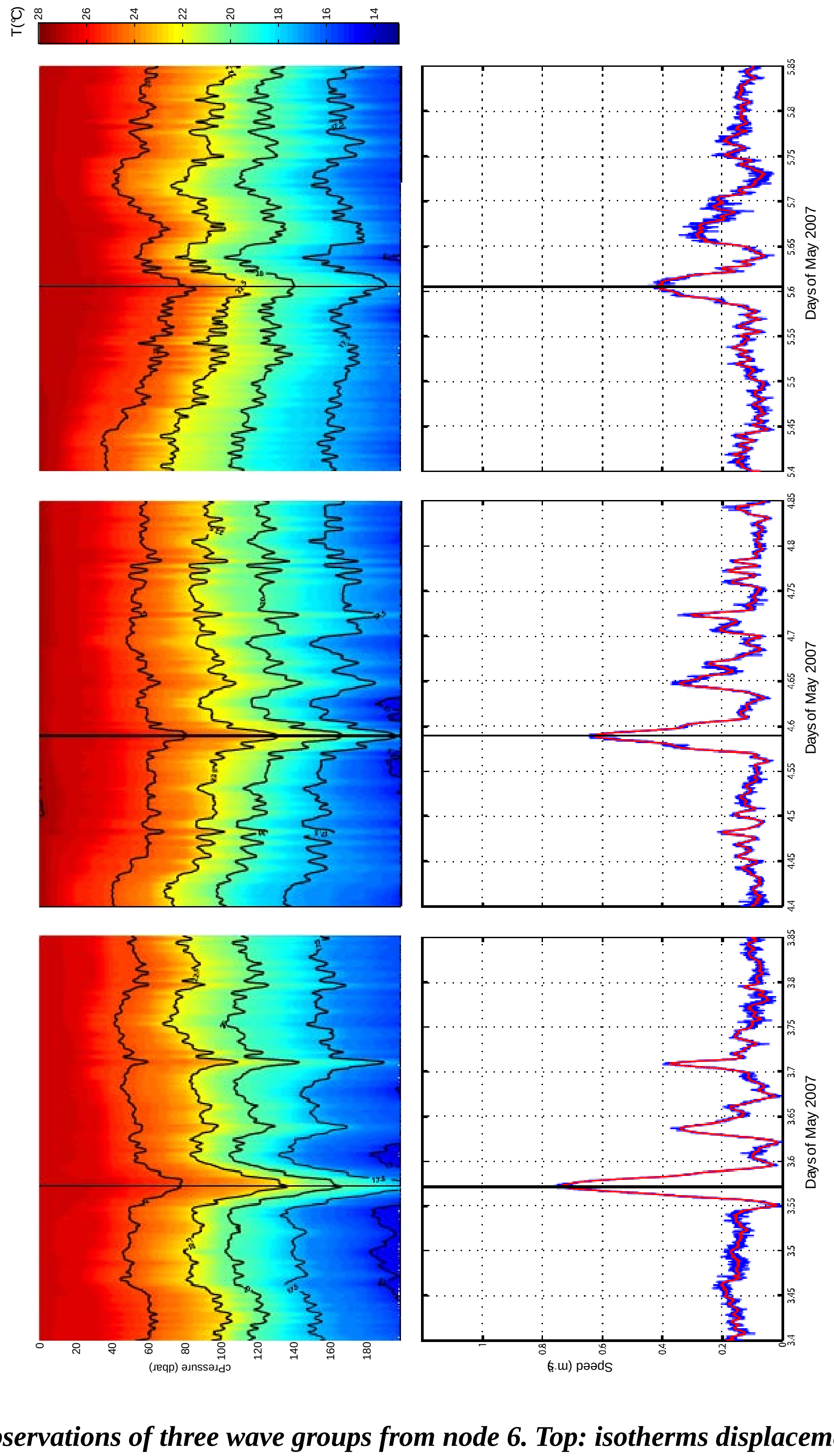

Figure 6: Observations of three wave groups from node 6. Top: isotherms displacement. Bottom: speed of the ADOS-V from GPS (blue are the 1 s data, red are the 30 s running averaged data). Data are plotted as time-series relative to the drifting instrument.

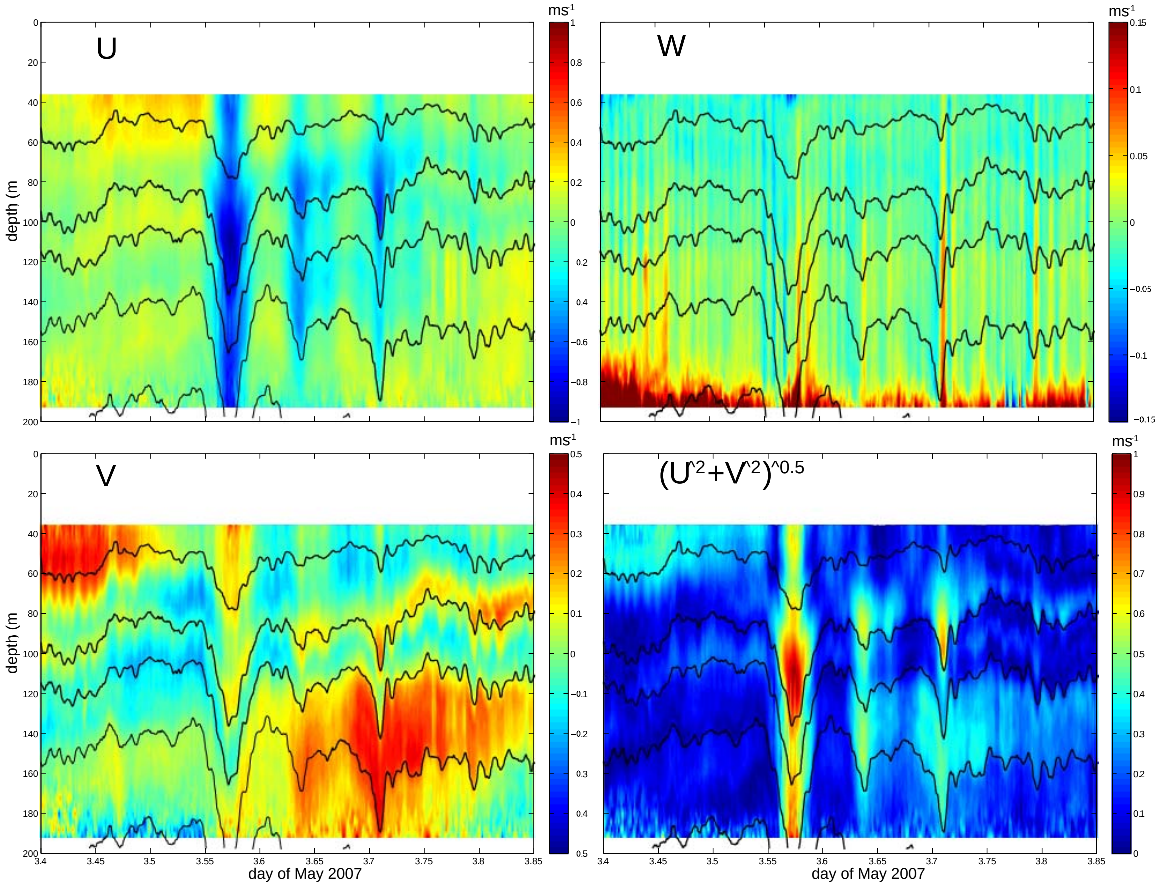

Figure 7. Three-dimensional absolute velocity profiles and horizontal flow speed measured from node 6. The following isotherms are also shown: 25°C, 22.5° C, 20° C, 17.5° C and 15° C. U, V and W are the eastward, northward and vertical upward velocity respectively

However, when the dynamics of the waves is of concern, as it is the case here, current meters and temperature sensors must of course be used, which adds to the overall cost of the equipment.

Table 1. Speed and direction of propagation for the two main waves of group 1

LIW group 1	Speed (m s^{-1})	Direction (°N)
Wave 1	2.80 +- 0.02	279.8 +- 0.5
Wave 2	2.60 +- 0.03	287.1 +- 0.7

Table 2. Same as table 1 but for wave group 2

LIW group 2	Speed (m s^{-1})	Direction (°N)
Wave 1	2.84 +- 0.03	282.6 +- 0.6
Wave 2	2.47 +- 0.05	285 +- 1

Table 3. Same as table 1 but for wave group 3

LIW group 3	Speed (m s^{-1})	Direction (°N)
Wave 1	2.79 +- 0.09	275 +- 3
Wave 2	2.57 +- 0.03	281 +- 1

The leading waves of each observed group travelled with a local speed of 2.8 ms^{-1}, which is remarkably close to the phase speed of first mode baroclinic semidiurnal tide computed from the CTD-derived density profiles, which is 2.79 m s^{-1} (Dr. V. Sheremet, 2007, pers. comm.). The local direction of propagation of the waves is slightly to the north-west. The second wave of each group always travelled slower than the first by about 0.2 ms^{-1} and its local direction is rotated from 3° to 7° to the north of the direction of the first wave. In both cases the horizontal velocity field at the trough of the wave is in the direction at which the wave propagates.

The waves groups do not travelled as a series of steady, amplitude ranked depression waves, and significant differences occurred over short spatial and temporal scales in the thermal and flow structure of the primary wave (along the front) and of the secondary waves (both along and across the front). A third (and sometimes other) smaller depression waves appeared at times throughout the ADOS-V array, but they were short-lived or had spatial scales smaller than the array separation, since they could hardly be tracked between adjacent nodes (not shown).

The time of arrival of the wave groups was very close to the (or multiple of) the M2 and K1 tidal periods, which are the dominant tidal constituents of the SCS and is qualitatively consistent with generation of LIW by interaction of the internal tide with the topographic features of the Luzon Strait.

CIRCULATION OF THE CHANGJIANG DILUTED WATER IN THE EAST CHINA SEA

- **Fresh water input by Yangtze River runoff**
  In monsoon period in the northeastern Asia, the large amount of fresh water poured into the East China Sea by the Yangtze River. The monthly mean runoff rate reaches 50,000 m^3/sec in July and it is one of the largest fresh water inflow by the river in the world.

- **Dispersion to the Yellow Sea and JES**
  The fresh water from the Yangtze River is mixed with the sea water and forms the Changjinag Diluted Water (CDW) in the East China Sea. Part of the CDW disperses into the South Sea of Korea and then to the Japan/East Sea in August and September. It also flows to the Yellow Sea. The circulation pattern differs by month (Figure ?) and it mostly depends upon the wind pattern.

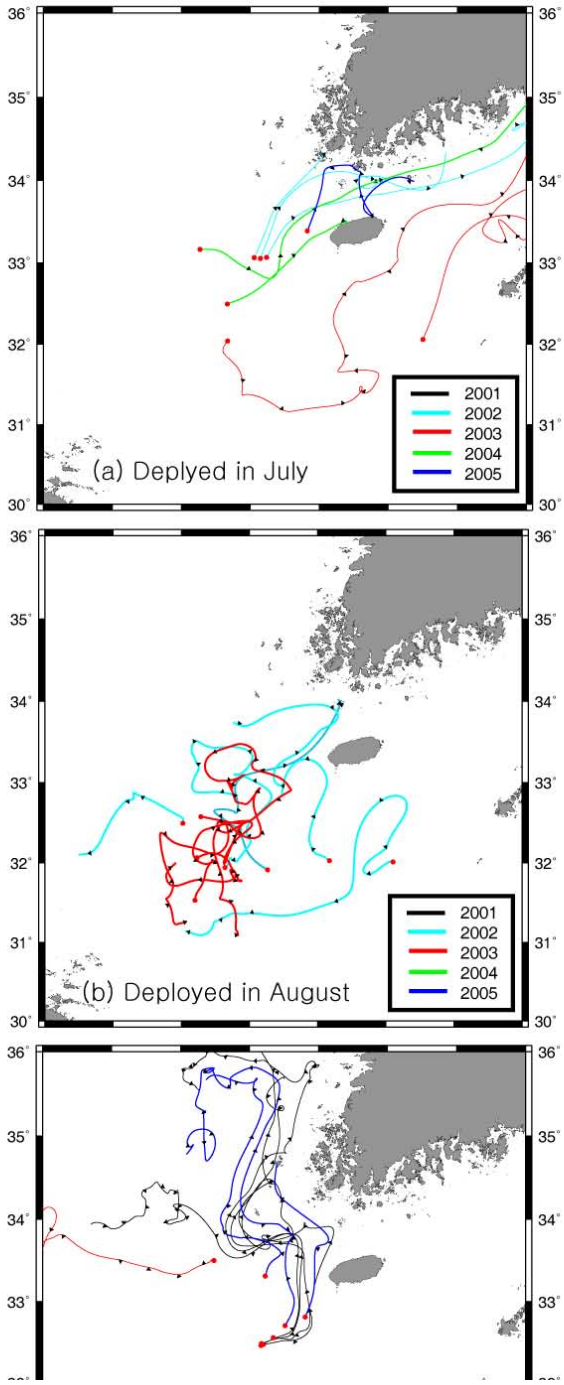

Figure 8: Drifter tracks deployed in the ECS.

- **Numerical modeling using ROMS**
  The ECS circulation in summer is mostly wind-driven and wind-driven current modeling in the highly stratified, shallow and near-coastal regions was attempted using ROMS. The model was driven by 6 hourly Quikscat blended NCEP wind and circulation from ROMS with KPP mixing scheme was not satisfactory compared to the observed current from drifters. The amplitude of observed current and model current were similar but the modeled current was 90° right of the wind instead of observed 45° angle. We are developing new mixing scheme for wind-driven current in this dynamically complicated region.

IMPACT/APPLICATIONS

The drifter data were placed on the GTS for use by global scientific community.

TRANSITIONS

None

RELATED PROJECTS

NOAA/OGP funded the “Global Drifter Program”; (ONR) “Real-Time Drifter and ADCP V(z) Observations of Kuroshio Intrusions on East China Sea Shelf”

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